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ESTABLISHING TUNA AND OTHER PELAGIC FISHES IN PONDS AND TANKS

SPECIAL SCIENTIFIC REPORT: FISHERIES No. 71

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE

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Washington, D.C.
February, 1952

United States Department of the Interior, Oscar L. Chapman, Secretary
Fish and Wildlife Service, Albert M. Day, Director

ESTABLISHING TUNA AND OTHER PELAGIC FISHES IN PONDS AND TANKS

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Special Scientific Report: Fisheries No. 71

Note.--This report is also Contribution No. 18,
Hawaii Marine Laboratory, University of Hawaii

WASHINGTON : FEBRUARY 1952

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During 1951, attempts were made to catch various species of tuna, transport them in a ship's livewell, and establish them in ponds and tanks at the Coconut Island branch of the Hawaii Marine Laboratory. The objective was to provide specimens for a study of the reaction of tuna to various types of stimuli.

The work was undertaken under contract (No. I6fw-13331) between the University of Hawaii and the Department of the Interior, Fish and Wildlife Service, Pacific Oceanic Fishery Investigations.

FISHING

Fish were caught by surface trolling from the University's 46-foot vessel, the Salpa (fig. 1). Fishing took place exclusively in an area centered off Mokumanu (Bird) Island, near Kaneohe Bay (fig. 2). Most of the fish were caught within 2 miles of the island.

In trolling, six lines were used, two (90 feet long) from each of two outrigger poles, and one (30 feet long) from each side of the stern. A variety of relatively small lures were used as follows: usually greenish or brownish, pliable-rubber imitation squid on the outside outrigger lines; gray or red, metal-headed imitation squid with white rubber arms on the inside outrigger lines; and red or white, metal-headed, feathered jigs on the stern lines. For the most part, small (No. 3 or 5, Japanese) double, barbed hooks were used with the lures. Both lures and hooks were small because small fish, not over about 8 pounds in weight, were desired. It has been our experience that large fish will take both large and small lures, but that small fish will usually take only small lures. Moreover, the small hooks caused less damage to the mouth parts and head of the fish than large hooks. Single barbed and barbless hooks were tried but discarded as almost invariably the hooked fish escaped before it could be landed.

Sixty fishing trips were made from January 18 to October 18, 1951, each trip lasting for about $2\frac{1}{2}$ hours, usually from 7:30 a.m. to 10 a.m. Fishing time was recorded as the interval between leaving and returning to No. 1 buoy (fig. 2). In trolling, all members of the crew (usually three in number) scanned the waters for active flocks of terns and boobies, which might be feeding above tuna schools. When an active flock was located, the Salpa headed towards it and trolled around the fringe of the flock, occasionally cutting through it. Usually fish were caught on one or several of the lines during this maneuver. Occasionally tuna and dolphin were caught when no active bird flocks were seen. Occasionally also, the dolphin catch was increased by towing one hooked fish astern at slow speed. This attracted the school to the stern and enabled more fish to be caught either with the trolling lines manipulated by hand so that the lures were in the school, or with regular tuna poles (June 1951) which were used only on such occasions. The speed of the Salpa in normal trolling operations was from 6 to 7 knots.

Table 1--Fishing record of the Salpa, January 18 to October 20, 1951

Month	Number of trips	Number of fish caught								Trolling hours	Mean catch per hour
		Skipjack	Frigate mackerel	Tunny	Yellow-fin	Wahoo	Dolphin	Jack	Total		
January	2	-	-	-	-	-	-	-	-	3-3/4	0.00
February	3	2	-	-	-	-	1	-	3	6-1/2	0.46
March	3	1	-	-	-	-	1	-	2	7-1/2	0.27
April	4	3	-	-	-	1	6	-	10	13-3/4	0.73
May	8	23	1	5	-	-	24	1	54	21-1/2	2.51
June	9	38	12	9	14	-	13	-	86	22-3/4	3.78
July	8	24	1	3	4	-	16	-	48	20-1/4	2.37
August	9	38	4	15	3	-	23	-	83	24-3/4	3.35
September	8	19	4	21	14	1	2	-	61	21-3/4	2.80
October	6	1	-	11	10	-	11	1	34	15-1/4	2.23
Totals	60	149	22	64	45	2	97	2	381	157-3/4	2.42

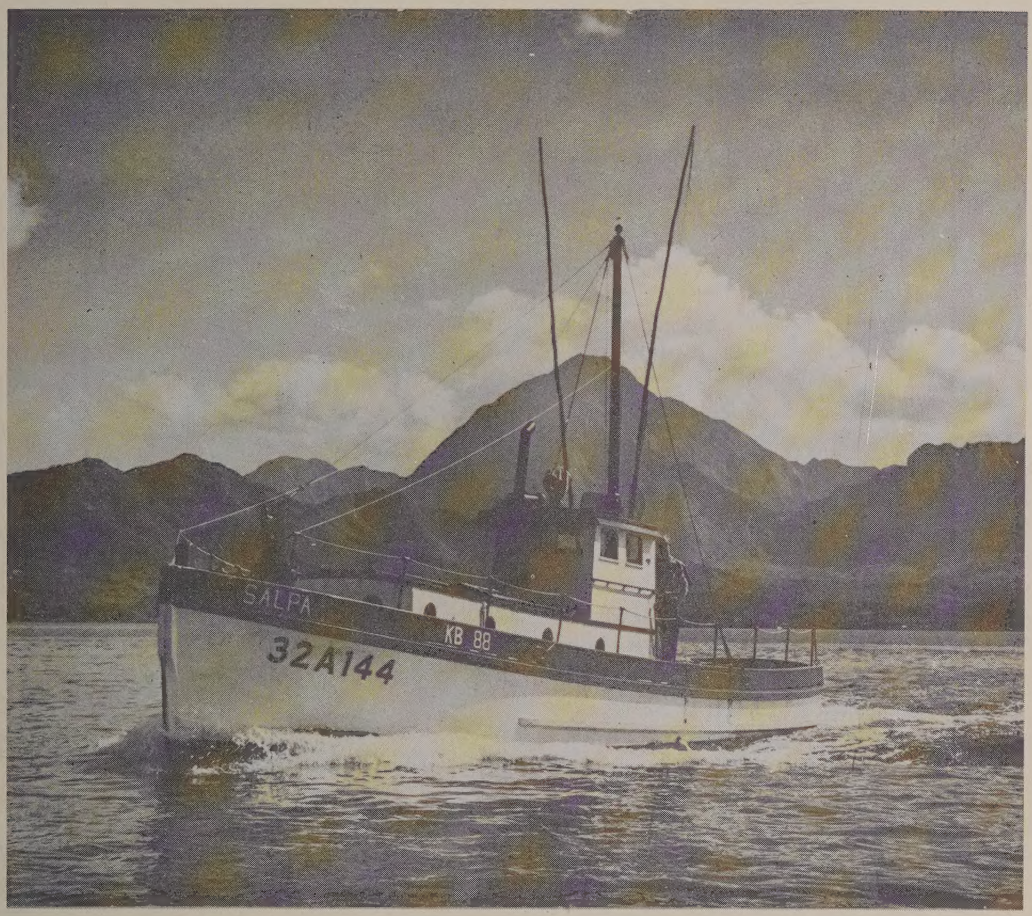

Figure 1. The 46-foot vessel, **Salpa,** used in catching tuna and other pelagic fish. The trolling poles are lowered when fishing.

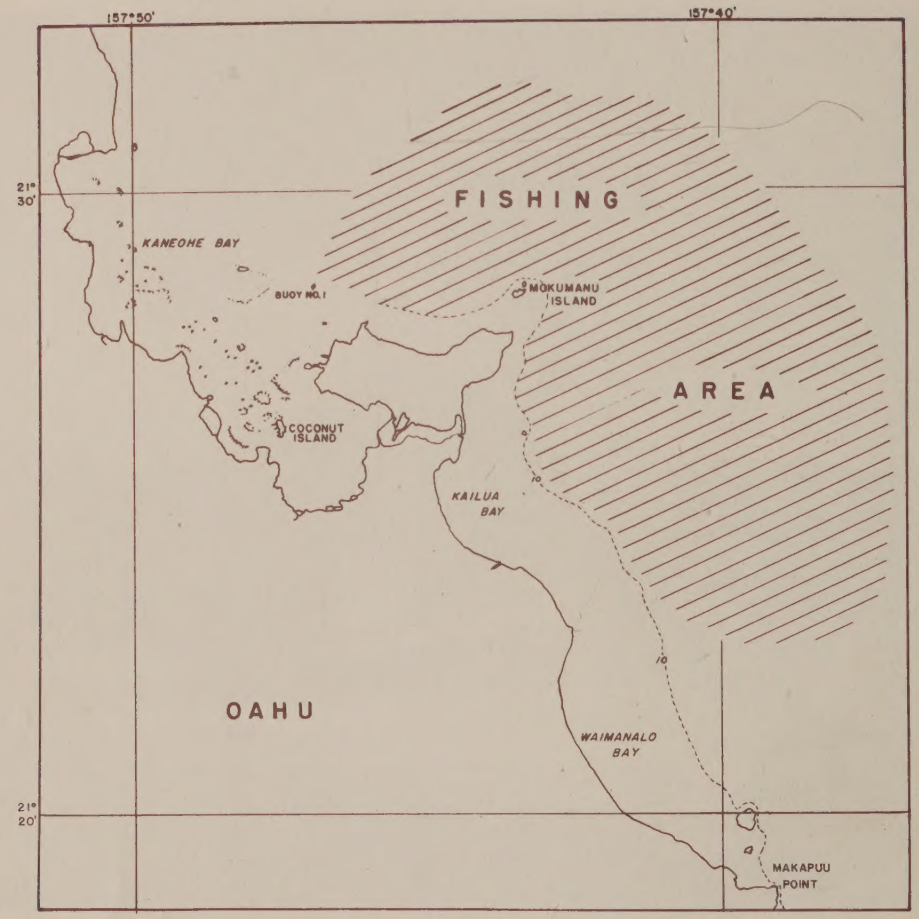

Figure 2. Fishing area off the easterly coast of Oahu, Territory of Hawaii.

Statistics of catch and effort are summarized in table 1. The catch consisted of 381 fish of which 280 were tuna (Thunnidae)[1]. Of the tunas, there were 149 skipjack or aku (Katsuwonus pelamis) ranging from $2\frac{3}{4}$ to $10\frac{3}{4}$ pounds (41 to 61 cm., fork length); 22 frigate mackerel (Auxis thazard) ranging from 1 to $2\frac{1}{2}$ pounds (32 to 37 cm.); 64 "little tunny" (henceforth called "tunny") or kawakawa (Euthynnus yaito) ranging from 1 to 15 pounds (about 37 to 58 cm.); and 45 yellowfin or ahi (Neothunnus macropterus) ranging from 1 to $8\frac{1}{2}$ pounds (29 to 58 cm.). Among the other fish, there were 2 wahoo or ono (Acanthocybium solandri, included by Brock (1950) in Thunnidae of 20 and $23\frac{1}{2}$ pounds (121 and 123 cm.); 97 dolphin or mahimahi (Coryphaena hippurus) ranging from about $1\frac{1}{2}$ to 32 pounds (about 45 to 122 cm.); and 2 jack or omilu (Caranx stellatus ?), both of about 4 pounds.

As shown by the mean catch per hour's trolling, fishing was very poor during January, February, and March; it improved during April; it was relatively good from May through October, with June and August the best months. Skipjack and dolphin were caught throughout February to October, "runs" appearing for 2 or 3 weeks at a time, and then disappearing. Frigate mackerel, tunny, and yellowfin were caught sporadically from May or June to September or October. The fishing record compares favorably with that reported by Welsh (1950) who used the same fishing method and the same vessel (in part) and who fished in the same general area (for the most part). His mean catch per hour amounted to 1.79 fish for the period March 1948 to June 1949, whereas ours was 2.42 fish for the period January to October, 1951. However, he caught relatively more tunny and relatively fewer skipjack; he encountered the best fishing during October.

HANDLING AND TRANSPORTING THE FISH

When the fish took the lures, they were hauled aboard and were either killed or placed in the livewell, depending on the species, size of the fish, and the extent of injury from the hook. Many of the fish, especially the larger ones, were hooked through the eye, through the nose, or deep in the throat, so that they were fatally injured. Those which were lightly hooked through the jaws and were judged likely to survive, were placed on the deck or in a canvas cradle or they were held in the hands of a second person (the method depending on the size of the fish and on the available help) for rapid but careful removal of the hook. Often the hook could be removed with but small damage to the fish if its mouth was held open by a second person. If after this operation the fish was judged to stand a reasonable chance of survival, it was placed in the livewell. Otherwise, it was killed and thrown into the fish locker. It was found unwise to place injured, bleeding fish in the livewell: their violent movements and the resulting bloody, murky water excited uninjured fish and caused them to damage themselves on the sides of the well.

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[1] For the most part, the classification and nomenclature used by Brock (1950) was followed.

Some of the fish, particularly skipjack and dolphin, threshed violently when landed on the deck. A light canvas was thrown over the dolphin while the hook was being removed. An attempt was made to anesthetize skipjack to facilitate the removal of the hook, by placing them in a 1-percent solution of urethane (Gerking 1949) which was contained in a tank on deck. Five fish were tried, but all died. Further attempts at using urethane were not made because of the difficulty of working on a plunging deck, of overcoming the large oxygen demand of the urethane solution, and of keeping the solution at the same temperature as the seawater (about 25°C.) when exposed to the hot sun.

The livewell of the Salpa (fig. 3) is built within the hull with an opening on deck, and its interior is painted white. It is $67\frac{1}{2}$ x 43 x 32 inches, with a square opening of 30 x 30 x 7 inches, the upper part of which is flush with the deck. Above deck, the opening is encased to a height of 10 inches with a removable square frame, the top of which has a cover of spaced wooden slats. When full, the livewell holds 424 gallons of seawater. The water is pumped to an inlet at the bottom of the tank at a rate of between 20 and 40 gallons per minute, depending on the mechanical condition of the pump and the speed of the ship's engine when under way. When the engine is idling, the rate of flow is much less--about 5 gallons per minute. The outlet is just below deck level, part way up the after side of the opening. The relatively small exposed area of water surface prevents excessive slopping of the water in the well when the ship is heaving. On occasion, particularly when several fish were in the well, or when the pump was not operating to capacity, oxygen was bubbled into it by means of two gas disseminators connected by rubber hose to a large tank of compressed oxygen. This procedure is believed to have maintained the oxygen tension in the well at a high level, although no measurements were made.

After noting that the tunas, in particular, tended to bump the corners of the well, baffles (18 x 32 inches) were placed across the corners. The resulting octagonal shape of the well induced the fish to travel in a circle, and considerably reduced the tendency to bump the sides.

Skipjack

Attempts at transporting skipjack were unsuccessful. When landed, many of the fish gave convulsive shudders, bled at the gills, and died within 3 or 4 minutes. Those which did not behave in this fashion and were placed in the livewell, swam rapidly (at more than 6 feet per second) and frequently rammed head-on into the sides. The behavior can best be described as "frantic." After they rammed the sides, they would sink slowly to the bottom of the tank, recover, and repeat the performance until they died. Frequently they would bleed at the gills and this would temporarily pollute the water. Those which did not ram the sides after the baffles were used, swam rapidly and frantically until they reached a state of exhaustion and died. All fish, except one, died within 10 minutes after being placed in the livewell; oxygen, when used as described above, did not help to any noticeable extent.

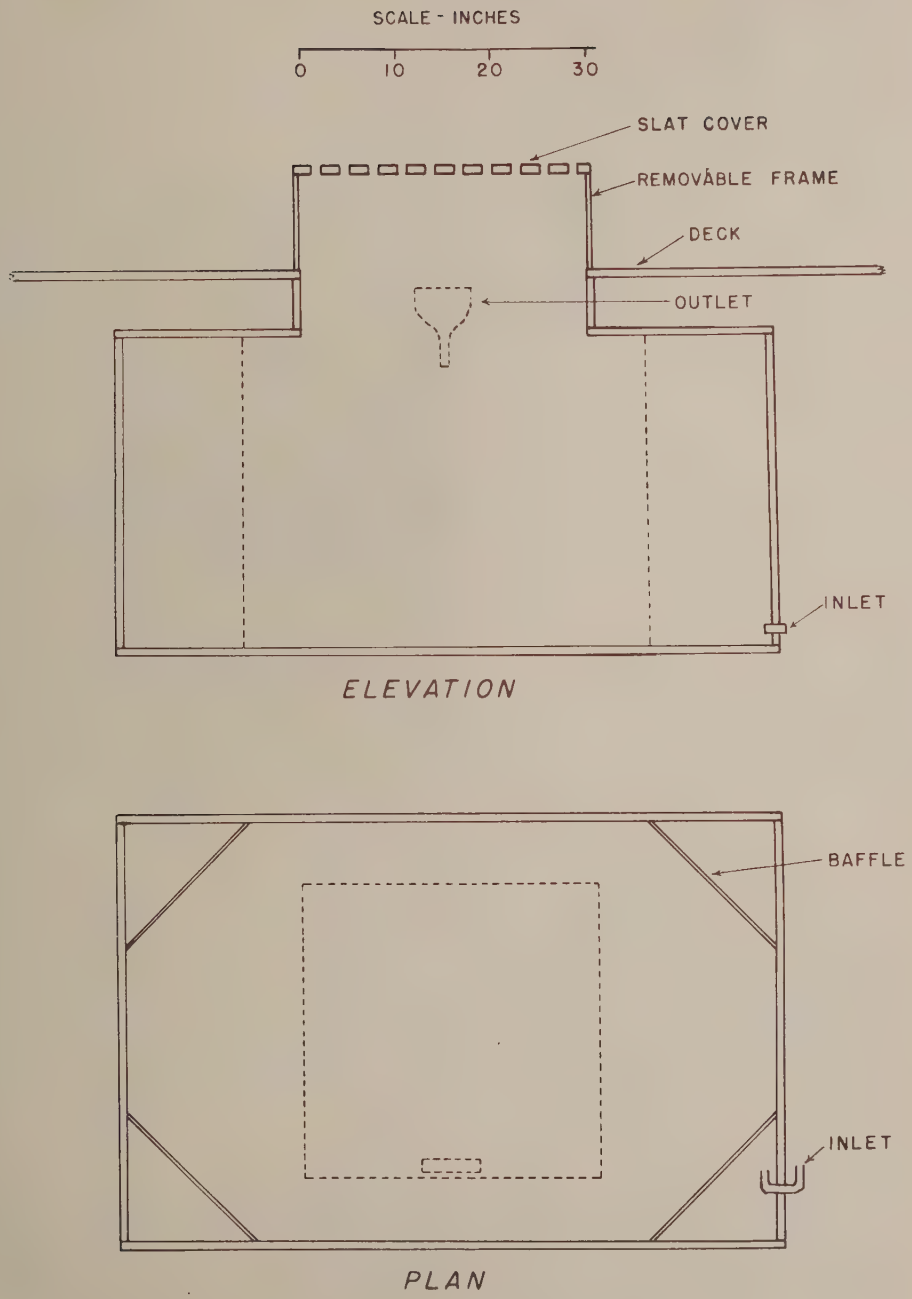

Figure 3. Diagram of the livewell of the **Salpa.**

Only one skipjack (5 pounds) survived the trip from the fishing grounds to shore. This fish fell from the hook when landed, and was placed immediately in the livewell.

Frigate mackerel

Of these small fish, 6 out of 22 were successfully transported to shore. Their behavior on deck and in the livewell was very similar to that of the skipjack, excepting that profuse bleeding at the gills did not take place. This, together with the greater swimming room which resulted from their smaller size, doubtless accounted for the greater success as compared with skipjack. However, those which survived the trip were frequently bruised and battered on arrival.

Tunny

The catch comprised two groups, large fish ranging from 4 to 15 pounds, which were caught early in the season, and small fish ranging from 1 to 3 pounds, which were caught later in the season. The large fish were damaged frequently in attempting to remove the hook. Of the 36 caught, 9 (4 to 7 pounds) were brought back alive and in fair condition. The small fish, on the other hand, were usually hooked lightly and could be transferred quickly to the livewell. Of the 28 small fish caught, 23 (1 to 3 pounds) were successfully transported to shore. During the trip they became lighter in color. Frequently, marks caused by handling showed up as dark blotches against the light background. These marks, caused by disturbance of the epithelial covering of the scales, disappeared after 1 or 2 days in captivity.

In the livewell, the tunny swam somewhat more slowly than either the skipjack or the frigate mackerel, the large fish travelling at about 4 and the small fish at about 3 feet per second. As might be expected, swimming speed gradually decreased with time, as the fish became accustomed to the livewell. Occasionally, the large fish would bump the sides of the wall; the small ones seemed able to keep clear. When both large and small fish were present, they tended to swim as a school, the large ones keeping to the outside and the small ones to the inside of the circular course.

Yellowfin

Apart from 3 small fish between 1 and 2 pounds, the 45 yellowfin caught during the fishing period were from 5 to 8 pounds in weight. Of the total number taken, 27 were brought back alive, 7 or 8 died during transport, and the rest were fatally injured on capture. Despite their relatively large size, they swam slowly and leisurely in the livewell at the rate of about 3 [redacted] feet per second. Only rarely did they bump the sides. Their behavior in the well was the most satisfactory of the four species of tuna.

Other fish

Dolphin, up to 5 or 6 pounds in weight, were readily transported in the livewell. Like the yellowfin, they swam slowly and leisurely, readily avoiding the sides. Of 47 fish caught between February 1 and July 19, 26 were brought back alive. The others, mostly large fish over 7 pounds, were killed on capture, either because they were badly hooked or because they were too large for the livewell--they are relatively long for their weight. No serious attempt to transport dolphin was made after July 19. A few were brought in during August and October.

The two large wahoo were gaffed on capture. The two jacks were transported in the livewell without any difficulty--they are relatively hardy fish.

ESTABLISHING THE FISH IN CAPTIVITY

On arrival at Coconut Island, the fish were transferred by dipnet to one of two ponds (No. 1 or No. 5) or to a concrete tank. The general location of the ponds and the tank is shown in figure 4.

Pond No. 1

Attempts were made first to keep the fish in pond No. 1. This is about 50 feet wide and 100 feet long, with a maximum depth at the center of about 4 feet at low tide and 7 feet at high tide. The bottom is of silt, studded with a few live coral heads, and the sides are of dead coral heads piled to form a wall. Circulation is effected by tidal currents through screened gates on each side. The stern of the Salpa could be brought within 40 feet of the pond (fig. 4), so that the fish were out of water for only a few seconds during transfer.

During May and June, three frigate mackerel, one tunny, and six yellowfin were introduced to the pond. The frigate mackerel dashed wildly across and around the pond; one battered itself on the coral sides and died within a few minutes; the other two swam rapidly for a short time and then disappeared in deep water and were not seen again--presumably they also died within a short time. The tunny and the yellowfin swam rapidly around the pond, keeping about 1 foot below the surface and 2 feet from the sides. Frequently they would bump the coral sides, and occasionally they would become marooned on a coral ledge. The tunny died on the third day after introduction to the pond. Of the six yellowfin, one died immediately, one was not seen again, and presumably died within a few hours, two died during the first night, one disappeared after the second day, and one died during the third day. Presumably the carcasses of the fish which disappeared lodged beneath coral ledges and were eaten by eels, crabs, or other animals which were in the pond; they could not be found in diving with a face plate. The dead fish which were recovered were badly scraped and bruised from contact with the coral. A 100-watt light was used to illuminate the pond at night, but this did not seem to help very much. Attempts at keeping tuna in pond No. 1 were abandoned after June 13.

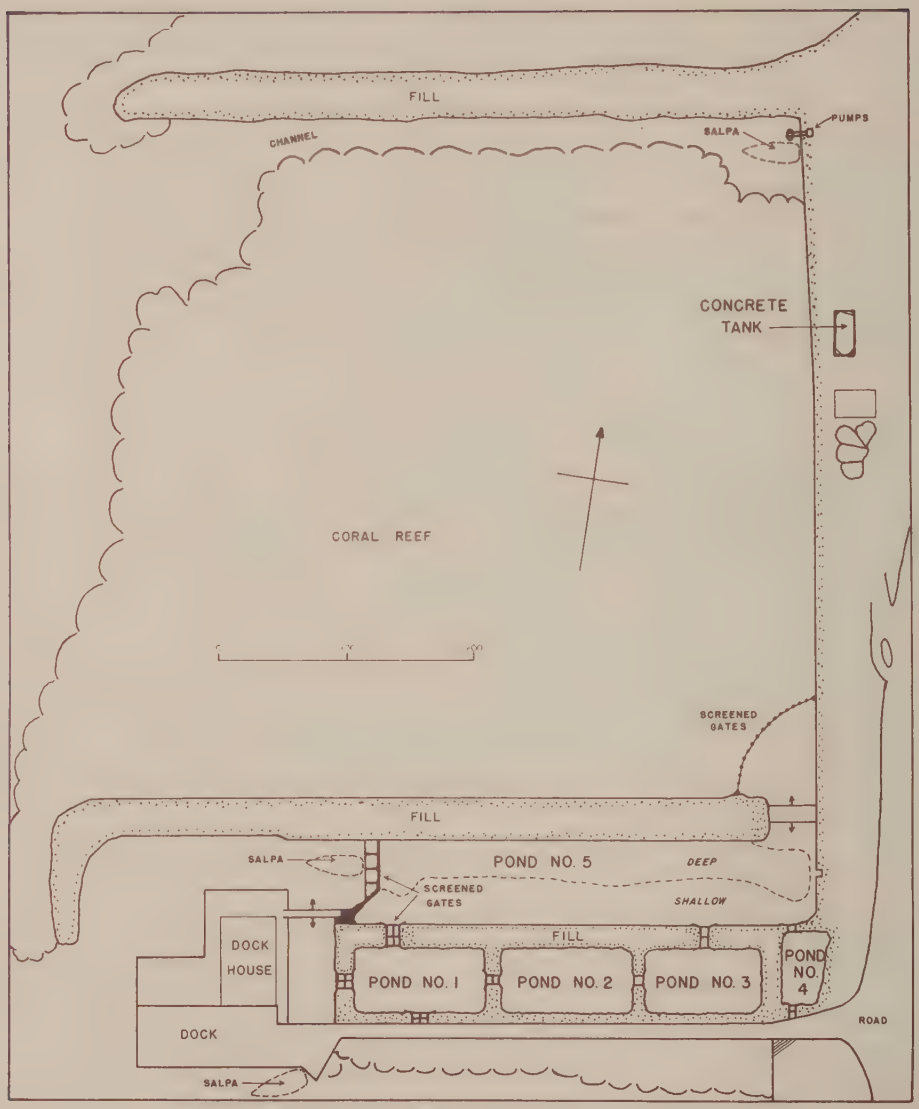

Figure 4. Relative size, design, and location of the ponds and tanks on the westerly side of Coconut Island. Dolphin were successfully established in pond No. 1, and tunas in pond No. 5 and the concrete tank.

Dolphin, on the other hand, were successfully established in pond No. 1, without the use of night illumination. When introduced, these fish swam slowly and leisurely at or close to the surface, creating a "bow-wave" as they travelled. They tended to avoid the sides and to keep to the center of the pond. They were encouraged in this tendency by placing a floating board, held by a line and anchor, near the middle--at sea, they are frequently observed to slowly circle a floating log, board, or coconut frond. The fish started to feed on strips of tuna flesh within a few days after they were placed in the pond. After starting to feed, they became quite "tame" and would mill around close to shore at the approach of an observer, expecting to be fed. They fed voraciously on tuna flesh, dead nehu (Stolephorus purpureus), and dead iao (Pranesus insularum), entering into rather unsuccessful competition with several jacks which were also present in the pond. They would also feed on schools of live nehu and iao which entered occasionally through the screened gates.

Despite the successful establishment of dolphin, mortality was high. A few died from injuries sustained during capture and transportation before they started to feed. Others came in contact with the rough coral walls during feeding, and died from injuries mostly to the head and jaws. Over the period April 10 to June 27, 26 fish had been placed in the pond and there were 14 survivors. No more were introduced until August 8 when there were 6 of the 14 still alive. Throughout August, September, and October the number was maintained at about five or six by adding one or two fish per month. No particular effort was made to build up a large population, as the fish were not being used for experimental purposes. At the time of writing (October 20, 1951), five fish were present, three of which had been living in the pond for at least 4 months.

The two jacks caught by trolling were placed in the pond on May 24 and October 18 respectively. Both have become established.

Concrete Tank

In the next attempt to establish tuna, a large rectangular concrete tank was used (fig. 5). The tank, partially sunk in the ground, was made of smooth, 6-inch concrete walls and bottom, and on the inside measured 34.7 feet long, 10.8 feet wide, and 3.8 feet deep at the north end and 4.0 feet deep at the south end. Its volume was 10,663 gallons. Running salt water was supplied by a pump at the rate of about 25 gallons per minute. The inlet, near the northwest corner, was directed horizontally (towards the south) at a depth of about $2\frac{1}{2}$ feet to promote circulation. The outlet was a notch cut in the top of the south wall at its center. Baffles, consisting of 3 x 4-foot galvanized iron sheets, painted white, were placed across the four corners. It is believed that these played an important part in the eventual establishment of the tuna, giving them reference points to mark the limits of the tank during the period of adjustment. The baffle in the northeast corner was later replaced by a larger one (3 x 10 feet), behind which was installed equipment for testing the

Figure 5. Concrete tank in which tunas were established. The top and sides are covered with chicken wire.

reaction of the fish to light. A $3\frac{1}{2}$-foot fence, with upright posts and horizontal, spaced plank bars, surrounded the tank on its upper edge. Towards the end of the summer, the fence was lined with chicken wire to keep the fish from jumping through, and the top was similarly covered to keep visitors from throwing stones at the fish. Two 60-watt bulbs were suspended above the tank and were lit from dusk to daybreak.

Transfer of the fish from the Salpa's livewell to the tank presented a problem as the only seaward approach was through a long, narrow channel which could be navigated only with difficulty (fig. 4). At first, the ship hove to at the entrance to the channel, the fish were placed in a square wire cage about 3 x 3 x 2 feet, and this was towed down the channel with a skiff, the trip taking about 15 minutes. On arrival at the shore, the fish were carried by dipnet to the tank, a distance of about 100 feet. Two dolphin were introduced in this manner and were not damaged to any great extent during transfer. However, of two frigate mackerel, one died while being towed and the other as soon as it was placed in the tank. Both were damaged from bumping and scraping against the sides of the cage. Next, a circular well of galvanized iron was built in a large skiff. The well was aerated from a small oxygen bomb, the fish were placed in it, and the skiff was moved down the narrow channel by means of an outboard motor. Two tunny and one yellowfin were transferred in this manner. Although they appeared to suffer but small damage during transfer, all three fish died, one tunny and one yellowfin that same night, and the other tunny during the second day.

It was finally decided that the Salpa could be navigated down the narrow channel during calm weather; it could be backed to the sea wall within about 130 feet of the tank. This procedure was followed in all subsequent transfers. Thus, double handling of the fish was avoided, although they had to be carried a greater distance in the dip net. At this time improvements were made in the tank. It was cleared of all rocks, clams, and fish such as jacks which might harm the tuna; the corner baffles and overhead lights were installed.

Over the period June 20 to September 2, the following fish were introduced to the tank: one skipjack (5 pounds), seven large tunny (5 to 7 pounds), five small tunny (about 2 pounds), and eight yellowfin (3 to 6 pounds).

The skipjack, introduced on July 25, dashed rapidly about the tank, ramming the sides. It died within an hour.

The seven large tunny, introduced at intervals between June 20 and September 2, swam more slowly than the skipjack and, for the most part, avoided the walls of the tank. However they all died--three after 24 hours, one after 36 hours, two after 48 hours, and one after 60 hours. For no apparent reason, and usually at night, a fish would suddenly become frantic, and would dash wildly up and down the tank, ramming the walls until finally it would die.

The five small tunny were introduced at intervals from August 27 to September 2. They swam at a leisurely pace around the tank, forming a school. The first fish, introduced on August 27, and three others introduced on August 29 started feeding on September 1, taking strips of tuna flesh. The fifth fish, introduced on September 2, started feeding the following day. They successfully pursued and devoured a small school of iao which was in the tank. However, during pursuit, one tunny leaped clear of the water and through the fence (before the chicken-wire screen was used). It was returned to the water, unharmed, by a member of our research group who happened to be present. No more livebait was placed in the tank for fear that the fish would injure themselves in chasing them.

The five small tunny are still alive and in good condition at the time of writing, and they apparently stand a good chance of surviving for an indefinite period[2]. They are fed strips of tuna flesh, dead iao, and dead nehu. They no longer exhibit fear at the approach of an observer, but mill around at his feet in anticipation of food. While feeding, they swim with great rapidity, taking food at or near the surface. They enter into active competition for food both with each other and with the yellowfin tuna which is also present in the tank. During the period of confinement, each is estimated to have gained about 1 pound in weight.

The eight yellowfin, which were introduced at intervals between June 20 and August 30, swam slowly and leisurely around the tank soon after being placed in it. Two died after 24 hours, two after 36 hours, and one after 60 hours. None of these fish had commenced feeding; they died in the same violent manner as described for the large tunny. One yellowfin (about 5 pounds) caught on June 20, started feeding on strips of tuna flesh on July 2, and is still alive at the time of writing. During its 4 months in captivity it is estimated to have gained about 3 pounds in weight. Like the small tunny, it has become quite "tame" and anticipates food at the approach of an observer. It shows a distinct preference for tuna flesh over dead iao or nehu. The remaining yellowfin (about 6 pounds) was caught on August 22 and started feeding on August 26. It became well established, usually swimming with and behaving similarly to the yellowfin just described. On September 4, however, it was found dead outside the tank--apparently it had leaped out of the water and through the fence while pursuing baitfish. The chicken-wire screen was installed at this time.

The five small tunny and the two yellowfin established in the concrete tank were subjected to a series of stimuli-reaction experiments by co-workers, the results of which will be reported at a later date.

2/ Three tunny died on November 11-12, 1951, following a period of cold, wet weather.

Pond No. 5

It was judged that the concrete tank would accommodate no more than about six or seven fish on a permanent basis. Moreover, a greater number than this would introduce complications in the experimental work which was being undertaken. Accordingly, on and after September 5, attempts were made to introduce tuna to pond No. 5 where it was hoped to build up a reserve population. This pond (figs. 4 and 6) is the largest available on Coconut Island. It is about 65 feet wide and 350 feet long. The west end is blocked from the seaward approach by a series of large screened gates, 4 to 10 feet wide, and 12 feet deep. At the northeast corner the pond extends under a bridge and is blocked from a shallow coral reef by 16 screened gates, 4 x 4 feet, arranged in a semicircle. About one-half of the pond, along the southern wall, is shallow, ranging from about 2 to 5 feet in depth. The other half of the pond, along the northern wall, is a deep channel which averages about 9 feet at low water and about 12 feet at high water. The bottom is of crushed coral, covered with silt, with a few living coral heads in the shallow parts. The walls are of smooth concrete. Screened gates in the south wall open to ponds Nos. 1, 3, and 4.

The Salpa was backed to the concrete framework forming the gates at the seaward approach and the tuna were dipped from the livewell and transferred directly to the pond. Present in the pond at the time the tuna were introduced were large schools of iao and nehu (which could pass through the meshes of the screening), one barracuda about 2 feet in length, several moray eels about 2 to 3 feet in length, and several small carangids, pomacentrids, and other reef fishes.

Over the period September 5 to October 18, the following fish were introduced: 1 frigate mackerel (about 1 pound), 19 tunny of which 1 was large (about 6 pounds) and the others were small (1 to 3 pounds), and 9 yellowfin (1 about 2 pounds and the rest 6 to 8 pounds). For the most part, the fish swam rapidly away from the gates on being placed in the water. The frigate mackerel and the tunny headed for the deep part of the pond whereas the yellowfin tended to swim leisurely 1 or 2 feet below the surface, at first following the walls but later keeping to the center. Once established and feeding, they could be attracted readily by food to the surface where they could be observed and counted.

The frigate mackerel was introduced on September 24 and disappeared 2 days later, at which time it was presumed dead. The large tunny was introduced on September 5. It was seen daily until September 10, at which time it was badly bruised and scarred, and had not started feeding. Presumably it died the following night.

The small tunny were introduced at intervals between September 27 and October 18. Only 5 of the 18 had died by October 20[3], 2 within

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[3] All but two tunny, and one of the yellowfin, died about November 10-12, 1951, following a period of cold, wet weather.

Figure 6. Pond No. 5 from the seaward approach.

NAVY—PEARL HARBOR, T. H.

a few hours and 3 after 2 to 6 days. Of the latter, 2 had been tagged experimentally by members of the Pacific Oceanic Fishery Investigations. Of the 13 fish which were still living, 4 were tagged and 1 had shed its tag. Each of the fish which survived started feeding on the day after it had been introduced. The tunny formed a compact school in the pond, cruising back and forth, and occasionally darting at great speed after baitfish. Except when feeding on baitfish, they tended to keep to the deeper part of the pond.

Seven of the nine yellowfin died before starting to feed, one (tagged) after 12 hours, four after 36 hours, one after 60 hours, and one (tagged) after 4 days. All or most of these fish died during the night. Of the two which survived, the first was introduced on September 5 and started feeding on September 12; the second was introduced on October 11 and started feeding on October 13. Both fish were still alive and in good condition on October 20. They swam either individually or together, sometimes schooling with the tunny. In general, they swam closer to the surface than the tunny and spent considerably more time in the shallow part of the pond.

DISCUSSION

Although trolling is a poor method of catching tuna and other pelagic fish which are intended to be kept alive, it was the only method which was practicable during the present work. As might be expected, many of the fish were fatally injured either from being dragged through the water, from being hooked through vital parts of the head and throat, or from being injured or suffocated during efforts to remove the hook from the mouth. In general, the larger fish were injured to a greater extent than the smaller. Skipjack suffered a much greater mortality during capture than other species because of profuse bleeding at the gills which, accompanied by convulsive shuddering, often occurred when the fish was landed.

It is believed that all species of tuna could be attracted to the stern of the vessel with livebait and could be caught with pole, line, and barbless hook. This method should greatly reduce the mortality from catching and handling--the fish would not be towed through the water, the hook could be removed readily, and the fish could be quickly transferred to the livewell from beneath the arm of the fisherman.

Although mortality during transportation in the livewell was reduced by installing corner baffles, which assisted the fish in following a circular course and in avoiding the walls, it was still considerable, particularly for skipjack, frigate mackerel, and large tunny, which still tended to bump the walls. Mortality during transportation might be reduced by the use of a larger livewell. This is indicated by results (unpublished) obtained with the Fish & Wildlife Service vessel Hugh M. Smith, in which 6 out of 13 skipjack (some tagged) were kept alive for 24 to 36 hours in the large (5,000-gallon) baitwell, after which time it was necessary to shut down the pumps (delivering

about 500 gallons per minute) and terminate the experiment.

With the methods which were used in the present work, only 0.7 percent of the skipjack, 27.3 percent of the frigate mackerel, and 25.0 percent of the large tunny were brought back alive. In contrast, the survival of small tunny was 82.1 percent and of yellowfin, 60.0 percent. Doubtless survival for all species could be increased by utilizing one or both of the suggestions made above. No particular difficulty was experienced in handling and transporting small dolphin, except in bringing them under control when they thrashed about violently on deck.

Our experience with pond No. 1 demonstrates the impracticality of attempting to keep tuna in an enclosure with rough, jagged sides. Not one fish of the several species of tuna which were introduced to this pond survived for more than 3 days. Most of them, bruised and torn on the head and body from contact with the coral, died within a few hours. Overhead lighting at night may have prolonged survival, but it did not prevent death. Dolphin and jacks, on the other hand, were able to avoid the sides fairly well, and eventually started to feed. However, even among the established dolphin, deaths occurred occasionally from bruises and cuts suffered by contact with the walls during the excitement of feeding.

Our experience with the concrete tank shows that it is possible to establish small tunny and yellowfin in a relatively small enclosure; this is a distinct advantage in making observations during experimental work. The success is attributed in part to the installation of white corner baffles which not only led the fish in a circle but also clearly delimited the tank boundaries. They seemed to be particularly important during the critical prefeeding period. Later, the baffles became covered with algal growth and were indistinguishable in color from the walls. The overhead lighting probably helped also, although its contribution to success was not investigated by removing the lights for fear of causing the death of the fish.

Small tunny and yellowfin were also successfully established in the large pond No. 5. Mortality during the prefeeding period occurred mostly at night, and might be reduced by illuminating the pond.

The small tunny became established in the tank and pond much more readily than the yellowfin, and once a school had been established, new fish started to feed during the second day of confinement. Of the 23 small tunny introduced, 18 (78.3 percent) became established. The yellowfin, on the other hand, did not start to feed for several days, and mortality was high during the period of adjustment. Of the 27 yellowfin which were introduced to the tank and large pond, only 4 (14.8 percent) started to feed and became established.

Neither the tank nor the pond used for the retention of tuna was of ideal size, shape, and construction. An ideal tank is envisioned as bowl-shaped, about 25 to 50 feet in diameter, and about

6 to 10 feet deep at the center. It might be made of concrete, with an inner face of glazed tile. Circulation and exchange of water might be effected by pumps of large capacity, with the inlet directed along the inside wall to produce a circular current. If the tank were located inshore, say on a coral reef, circulation might be accomplished by means of a propeller or paddle wheel installed in the screened opening, the sides of which would be tangential to the wall. A very strong current, which would promote rapid swimming and thus produce a large flow of water over the gills of the fish, may be necessary for the survival of fast swimmers such as the skipjack and frigate mackerel. It has been amply demonstrated that rapid swimming is not necessary for the survival of small tunny and yellowfin. However, with an arrangement such as that just described, it might be possible to arrive at an optimum current flow and thus an optimum swimming rate which might decrease mortality, particularly during the period of adjustment in the latter species.

No references to the establishment of tuna in captivity have been encountered in the literature, although it has been done in Japan and perhaps elsewhere. During a recent (1951) trip to Japan, Professor Iwao Miyake, University of Hawaii, reports having seen about 100 meji maguro (small black tuna, Thunnus orientalis) living in an inshore enclosure made of webbing. The enclosure, which was about 90 feet long, 30 feet wide, and from 3 to 15 feet deep, was located at Mitohama, near Shizuoka. Other visitors to Japan have reported seeing tuna confined in a circular tank.

The present work, while only moderately successful, has demonstrated the feasibility of holding two species of tuna in confinement for an extended period of time, thus providing material for studies of their behavior, feeding, food consumption, growth, and reaction to stimuli under experimental conditions. It has also indicated ways in which the methods of catching, handling, transportation, and retention might be improved for greater survival.

ACKNOWLEDGMENTS

Much credit for success must be given to Mr. Lester Zukeran, skipper of the Salpa, who conducted the fishing expeditions with great skill and patience, and who aided in the handling and transfer of the fish. Credit must also be given to Mr. Charles Nakamoto for assistance in fishing, and especially for the care and feeding of the fish in captivity. To these employees of the Hawaii Marine Laboratory, and to members of the staff of both the University of Hawaii and the Pacific Oceanic Fishery Investigations who assisted occasionally in fishing, I wish to express my sincere thanks.

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